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EXPERIENCE IN RECONSTRUCTING A GLASS-MAKING FURNACE

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The concept of upgrading a glass-making furnace and the practicality of the engineering solutions used for this purpose are examined. It is shown that mathematical simulation of the thermophysical processes involved in glass-making would be helpful for furnace reconstruction.

The "Kishinev Glass Works," a state enterprise, is the leading BT-1 glassware manufacturer in the Republic of Moldova. It produces mainly four recuperative glass-making furnaces and eleven glass-forming machines (nine sectional and two rotor types). The glass-making furnaces (three horseshoe-fired and one side-fired) are heated with natural gas without additional electric heating.

The horseshoe-fired glass-making furnace No. 2 was constructed in 1996 following the Institute's "Yuzhgiprosteklo" project. The nominal capacity of the furnace is 171 tons/day and the area of the melting tank is 77.9 m^2. Three IS-8 DG glass-forming machines, manufactured by the German company "Emhart," are installed in the furnace. The average capacity of the furnace over a campaign is 130 – 135 tons/day with specific heat consumption for glass-making 8580 kJ/kg.

The inadequate capacity, the unstable quality of the glass mass, and the high specific consumption of heat forced the enterprise in 2001 to upgrade the design of the furnace, increasing the area of the melting tank to 86.6 m^2. The furnace capacity increased to 140 tons/day and the specific heat consumption decreased to 8130 kJ/kg.

The results achieved did not fully solve the problems of providing the machines with high-quality glass mass and reducing heat consumption substantially. Consequently, in 2006 the management decided to reconstruct furnace No. 2, during a cold-maintenance period, with the following objectives:

to increase the capacity of the furnace up to 200 – 230 tons/day in order to provide a full-value load to the IS-8 DG three glass-forming machines, whose capacity is 60 – 80 tons/day depending on the product assortment; if the existing area of the melting tank is maintained, the problem is to increase the specific output of glass mass from 1.6 to 2.3 – 2.7 tons/m^2 per day;

to decrease the specific heat consumption for glass-making to a level not exceeding 5200 kJ/kg; with the prices of imported natural gas remaining high and trending upward, reducing specific heat consumption becomes paramount for the economics of the enterprise;

to provide high-quality glass mass, making it possible to satisfy the ever increasing requirements of the enterprise's customers; the problem of glass quality is especially urgent for the manufacture of exclusive and exported articles, whose fraction of the overall production volume is much higher than that of the standard products.

The plans called for satisfying a number of additional conditions during period of cold maintenance performed on the furnace — the construction work was to be reduced in volume and completed more quickly. The main conditions were that the dimensions of the production body and the existing furnace or its substructures should remain unchanged. The connection of the feed channels of the glass-forming machines to the outlet pans of the product channel should remain unchanged. Thus, the total length of the furnace (from the recuperator to the feeder channel) was kept at 25 m. No provisions were made to install additional electric heating in the melting tank and the flow channel of the furnace. Given such stringent initial conditions, an unconventional approach to solving the technical problems of reconstructing the furnace was proposed [1].

Analysis of the existing furnace structure showed that the implementation of its chief components (recuperator, burners, melting tank, channel, and product channel) does not

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TABLE 1.

Surface	Glass-mass surface temperature, °C	Masonry temperature, °C		Thermal resistance of the masonry, $(m^2 \cdot K)/W$	Heat flux density, W/m^2
		interior	exterior		
Crown	–	1250 – 1400	158.4 – 168.8	0.42	2610.9 – 2918.1
Channel side walls	1200 – 1380	1190.8 – 1372.6	125.3 – 141.3	0.93 – 0.68	1475.4 – 1820.9
Channel bottom:					
central zone	1300 – 1380	1295.9 – 1376.3	119.7 – 124.6	1.04 – 1.03	1136.8 – 1222.9
peripheral zones	1200 – 1300	1196.6 – 1297.1	108.0 – 113.9	1.17 – 1.14	945.0 – 1041.7

comport with the concepts of a modern glass-making furnace. Most problematic was the construction of the recuperators, whose size made it impossible to increase the packing volume to values characteristic for a high-capacity furnace — 2.7 – 2.9 m^3/m^2 melting-tank area. Maintaining the dimensions of the bottom plate and the glass-mass level marker, the interior volume of the recuperative chamber to be filled with packing material allowed for the ratio 1.71 m^3/m^2. The following measures were taken to intensify the operation of the recuperators.

Licht packing was replaced with TL 14/15 pottery clay packing with specific volume 0.371 m^3/m^2 and specific heating area 15.8 m^2/m^3. As a result, the contact surface area of the packing with the products of combustion on the exhaust side and air on the operating side of the furnace increased by 43.3% and comprised 10.04 m^2/m^2 melting-tank area.

The packing at the top (14 rows) is made of the materials PShAM-1 (87% MgO), the packing in the central and bottom parts is made of the materials MKV-72 (72% Al_2O_3) and ShV-42 (42% Al_2O_3), respectively. It should be noted that the materials used to make the packing do not completely match the operating conditions in high-temperature glass-making furnaces. These materials were chosen with an eye toward cold maintenance to be performed on furnace No. 2, excluding the possibility of acquiring pottery clay packing from producers in Western Europe or China and making use of the technical capabilities of the Borovich Refractory Works. To make sure that it can operate without hot maintenance for an entire furnace campaign the packing must be made of refractory materials which are more resistant to attack by the products of combustion. Examples are (top to bottom): QMZR-12 (78% MgO, 12.5% ZrO_2), QMZ-97 (96.5% MgO), QMZ-95 (94.5% MgO), QMZ-92 (92% MgO), and QMZR-12B (75% MgO, 10% ZrO_2).

The frequency with which the flame is redirected decreased from 30 to 20 min. This corresponds to the optimal conditions of heat transfer between the packing and gaseous media.

The pyrometric method used in furnace No. 2 to measure the temperature of the stack gases and the heating of the air does not permit evaluating these parameters correctly. The temperature of the stack gases before the stack is a more objective comparative characteristic of the operation of a recuperator. Practice has shown that when the measures listed above were instituted the performance of the packing could be increased substantially. Depending on the capacity of the furnace, the temperature of the stack gases was 120 – 150°C lower after maintenance.

The depth of upgrading of the output channel was much greater than for the recuperator. It is known that the functional purpose of this part of the furnace is not limited to delivering glass mass to the feeder channels. Calculations showed that with nominal capacity 200 – 230 tons/day the temperature of the melt at the exit from the furnace can reach 1350 – 1380°C. Along the path of the melt toward the exit pans of the output channel the glass mass must be cooled to a prescribed temperature at the entrance into the feeder channel (approximately 1200°C) and the proper conditions must be created in order for thermal homogenization of the glass mass to occur. Since the relation between the axes of the feeder channels and the axis of the furnace remains unchanged, the changes made to the construction of the output channel reduced to changing its width and depth and the construction of the structure at the top. Dividing the channel into zones made it possible to improve the system for heating and cooling the working space. The heat losses through the masonry were differentiated too (Table 1). Together with radiative cooling, the thermal insulation of different surfaces of the channel allowed for intense and controllable cooling of the surface of the glass mass. Conditions for decreasing the temperature gradient along the depth and width of the melt flow were created at the same time.

Even though the width of the output channel was increased from 800 to 1200 mm and the dimensions of the recuperator were kept the same (in the plan), the area of the melting tank was increased to 92 m^2 in the new layout of the furnace. The need to increase the surface area of the melting tank as much as possible was dictated by the desire to limit the specific extraction of glass mass to 2.5 $tons/m^2$ per day and thereby create objective conditions for furnace operation without additional electric heating. Decreasing the load on the refractories of the melting tank was also of considerable importance.

Before the melting part of the furnace was designed, the external heat exchange and the heat transfer and hydrodynamics of the melt in the melting tank were simulated mathe-

TABLE 2.

Surface	Glass-mass surface temperature, °C	Masonry temperature, °C		Thermal resistance of the masonry, $(m^2 \cdot K)/W$	Heat flux density, W/m^2
		interior	exterior		
Furnace crown	–	1450 – 1570	130.4 – 137.2	0.70 – 0.69	1866.6 – 2038.9
Wall of the flame space	–	1500 – 1570	112.5 – 117.0	0.94 – 1.12	1217.7 – 1305.4
Tank wall:					
cooled part*	–	1250 – 1450	183.8 – 202.6	–	17,182.0 – 20,411.0
central part	–	1450.0	114.4	1.07	1254.2
bottom part	–	1350.0	107.8	1.10	1125.6
Tank bottom:					
melting zone	1250 – 1400	–	113.3 – 122.4	1.11 – 1.08	1031.5 – 1183.1
fining zone	1400 – 1450	–	103.5 – 106.0	1.48	874.1 – 912.9

* The coefficient of convective heat emission into the cooled part of the furnace was 111.8 – 202.6 $W/(m^2 \cdot K)$.

matically. A mathematical model of the thermal functioning of a high-productivity glass-melting furnace was used for this purpose [2 – 4]. To decrease the volume of computations, a previously developed method for studying the heat transfer and hydrodynamics of the melt in glass-making furnaces was used to develop the simulation program [5 – 8]. The regularities observed in the effect of the structural and regime parameters of the furnace on the heat transfer and hydrodynamics of the melt made it possible to formulate a concept for redesigning the melting part of the furnace. It was determined that to attain high furnace capacity and thermal efficiency the flame space of the furnace and the melting tank had to be radically upgraded.

Analysis of the exterior heat transfer showed that the role of the heat generation zone (the working space of the furnace) is not limited to obtaining heat energy and organizing efficient heat emission to the surface of the tank. No less important is providing the optimal temperature distribution on this surface, corresponding to the conditions required for the optimal convection flows of the melt [5, 6].

In practice, it is necessary to attain in the furnace space not only complete combustion of a definite amount of fuel but also the optimal flame direction (toward the surface of the glass mass) and length. The optimal angle of attack of the flame, determined by the construction of the air channel (including its entry opening — inflow), the fuel feeding conditions, and the velocity characteristics of the air and gas streams, makes it possible to obtain a grazing motion of the products of combustion with respect to the heating surface [9 – 11]. This creates the conditions for organizing straight, directed, radiative heat transfer, where intense heat transfer to the surface of the glass mass is achieved at lower masonry temperatures. This is confirmed in practice by the operation of the furnace No. 2 after reconstruction. Thus, with approximately 2.2 tons/m^2 of glass mass extracted per day the maximum temperature of the inner surface of the crown does not exceed 1520°C.

The design developed for the burner setup makes it possible not only to optimize the direction of the flame but also to regulate the length of the flame within limits corresponding to the optimal temperature distributions on the surface of the glass mass [5, 6].

Analysis of heat transfer in and hydrodynamics of the glass mass in the melting tank showed that the structure of the convection flows, the number of times the melt circulates in the furnace, and the thermal uniformity of the melt at the exit from the furnace are all determined by a set of structural parameters of the melting tank, for example, the arrangement and shape of the loading pockets, the profile of the longitudinal section of the tank, the height and arrangement of the blocking sill, bubbling, and others. Together with optimization of the temperature field on the surface of the glass mass, these solutions make it possible to optimize the structure of the convection flows, increase the number of times the melt circulates in the melting part of the tank, and thereby create the conditions for intensifying the glass-making process. At the same time, optimizing the parameters of the blocking sill and the ratio of the tank depths before and after the sill create the conditions for intensifying the fining and homogenizing of the glass mass.

Together with what was said above, the technical solutions for the reconstruction of the furnace provided for decreasing the heat losses into the surrounding medium through all structural components of the melting part of the furnace. The initial conditions (in the simulation and the design) for the heat losses are presented in Table 2.

The capacity of the furnace has now reached 202 tons/day, i.e., it has increased by 44.3%. The specific heat utilization for glass-making has been decreased by 38.2% and does not exceed 5028 kJ/kg. The quality of the glass mass and the melting temperatures attest to the technical possibility of further increasing the specific production of glass mass. The calculations show that when the capacity of the furnace reaches 230 tons/day the specific heat consumption will be

4788 kJ/kg, which corresponds to the operational parameters of glass-melting furnaces with modern construction.

The results of the first months of operation of the glass-melting furnace No. 2 confirm the correctness of the technical solutions implemented in the reconstruction project. They attest to the effectiveness of mathematical simulation of the thermophysical processes involved in glass-making and the desirability of making mathematical simulation a separate stage in the general methodology of designing glass-making furnaces.

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